

# E<sub>OP</sub> & E<sub>P</sub> PROCESS FOR BLEACHING OF CHEMICAL PULP

## RELATED APPLICATION

This application claims priority from Provisional Application Serial Number  
5 60/271,987 filed on February 27, 2001.

## BACKGROUND OF THE INVENTION

Historically the treatment of wood chips to form a chemical pulp has been  
divided into two processes. The first process is pulping and the second process is  
10 bleaching.

Pulping is the changing of wood chips or other wood particulate matter to  
fibrous form. Chemical pulping includes partial removal of lignin and other  
materials associated with the wood.

Bleaching is the treatment of the partially delignified cellulosic fibers with  
15 chemicals to remove or alter the coloring matter associated therewith. Bleaching  
brightens the fibers in order to reflect white light more truly.

Throughout the evolution of pulp bleaching, caustic soda (NaOH) has been  
used as the primary alkali source in bleaching of chemical pulp. Caustic soda is  
a highly soluble alkali that readily provides an optimum reaction pH and facilitates  
20 the dissolution of lignin from pulp in pulp bleaching. Since caustic soda is a  
strong base, carbohydrate degradation can occur resulting in a decrease in pulp  
viscosity and an increase in chemical oxygen demand (COD).

In conventional pulp bleaching, a D- E<sub>OP</sub>-D-E<sub>P</sub>-D bleaching sequence is  
often employed for brightening chemical pulp. E<sub>OP</sub> bleaching typically utilizes  
25 hydrogen peroxide, oxygen, caustic soda and magnesium sulfate as the bleaching  
chemicals. E<sub>P</sub> bleaching typically utilizes hydrogen peroxide and caustic soda as  
the bleaching chemicals. Conventional E<sub>OP</sub> and E<sub>P</sub> bleaching suffer from the  
drawback of increased COD which is described above.

Accordingly, there is a need for a E<sub>OP</sub> and E<sub>P</sub> bleaching sequences which  
30 overcome the above-described drawback.

## SUMMARY OF THE INVENTION

This invention is directed to an  $E_{op}$  and an  $E_p$  process for bleaching chemical pulp which overcome drawbacks associated with conventional bleaching.

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The subject process comprises providing a bleached chemical pulp  
5 produced by bleaching sequences in which  $E_{op}$  and/or the  $E_p$  aqueous bleaching solutions employed therein include magnesium hydroxide in place of a substantial portion of the NaOH, and as a total replacement for any magnesium sulfate. The  $E_{op}$  aqueous bleaching solution can comprise a peroxide compound, an oxygen-  
10 containing material, sodium hydroxide and magnesium hydroxide, in the absence of magnesium sulfate. Alternatively, the  $E_{op}$  aqueous chemical solution for bleaching chemical pulp can comprise an  $E_{op}$  aqueous bleaching solution consisting essentially of a peroxide compound, an oxygen-containing material, sodium hydroxide and magnesium hydroxide. In any case, chemical pulp is bleached with an  $E_{op}$  aqueous bleaching solution to form an  $E_{op}$  bleached chemical  
15 pulp. The  $E_{op}$  aqueous bleaching solution of this invention can be employed in a D- $E_{op}$ -D- $E_p$ -D bleaching sequence. The subject invention is also directed to a bleaching sequence which includes the  $E_p$  bleaching of chemical pulp. The  $E_p$  aqueous bleaching solution can comprise a peroxide compound, sodium hydroxide and magnesium hydroxide, in the absence of magnesium sulfate. Stated another  
20 way, an  $E_p$  aqueous bleaching solution can be provided consisting essentially of a peroxide compound, sodium hydroxide and magnesium hydroxide. In certain bleaching sequences, for example, the  $E_p$  aqueous bleaching solution of the subject invention can be provided for bleaching  $E_{op}$  bleached pulp to form an  $E_p$  bleached chemical pulp. The  $E_p$  aqueous bleaching solution of this invention can also be  
25 employed in a D- $E_{op}$  -D-  $E_p$  -D bleaching sequence.

In the  $E_{op}$  and/or  $E_p$  processes of the present invention, the amount of sodium hydroxide in the  $E_{op}$  and/or aqueous bleaching solution is preferably not more than about 8 % by weight, more preferably not more than about 5 % by weight, and most preferably not more than about 3 % by weight, based on the O.D.  
30 weight of said chemical pulp.

Furthermore, the ratio of sodium hydroxide to magnesium hydroxide in said  $E_{op}$  aqueous bleaching solution is not more than about 5:1 (based on an  $OH^-$  molar ratio), preferably not more than about 3:1 (based on an  $OH^-$  molar ratio), and most preferably not more than about 1:2 (based on an  $OH^-$  molar ratio). As for the ratio of sodium hydroxide to magnesium hydroxide in said  $E_p$  aqueous bleaching solution, it is not more than about 1:1 (based on an  $OH^-$  molar ratio), preferably not more than about 1:3 (based on an  $OH^-$  molar ratio). Most preferably about 100% magnesium hydroxide is employed without substantially any sodium hydroxide.

Both the  $E_{op}$  and  $E_p$  bleaching processes of this invention preferably contemplates that the pulp viscosity of a final bleached chemical pulp is at least substantially the same as the pulp viscosity of a final bleached chemical pulp which is bleached with the same total amount of an  $E_{op}$  aqueous bleaching solution comprising a peroxide compound, oxygen-containing material, sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide, on the one hand, and/or an  $E_p$  aqueous bleaching solution comprising a peroxide compound and sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide, on the other hand. Pulp viscosity is measured in centipoises using the 0.5% CED viscosity test method described in TAPPI T-230.

Also, the preferred  $E_{op}$  process generates a bleach effluent which has a COD which is less than the COD of a bleach effluent from an  $E_{op}$  process which employs an  $E_{op}$  aqueous bleaching solution comprising the peroxide compound, oxygen-containing material, sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide. More specifically, the COD of the bleach effluent produced using the  $E_{op}$  aqueous bleaching solution of the present invention is preferably at least about 5%, more preferably at least about 8%, and most preferably at least about 10%, less than the COD generated by an  $E_{op}$  stage which uses an  $E_{op}$  aqueous bleaching solution comprising said peroxide compound, oxygen-containing material, sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide. COD is measured in mg/L using a HACH test kit.

Moreover, the bleached chemical pulp of a bleach sequence containing the subject process preferably has a final ISO brightness (% ISO) of which is at least substantially the same as the final ISO brightness (% ISO) of bleached chemical pulp which is bleached with the same bleach sequence but with an  $E_{op}$  aqueous

5 bleaching solution comprising a peroxide compound, oxygen-containing material, sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide, on the one hand, and/or an  $E_p$  aqueous bleaching solution comprising a peroxide compound and sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide, on the other hand.

10 ISO brightness is measured using the test method described in TAPPI T-452.

The process of this invention also produces a bleached chemical pulp having a preferred wet zero span tensile strength which is at least substantially the same as the wet zero span tensile strength of bleached chemical pulp which is bleached with the same total amount of an  $E_{op}$  aqueous bleaching solution

15 comprising a peroxide compound, oxygen-containing material, sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide, on the one hand, and/or an  $E_p$  aqueous bleaching solution comprising a peroxide compound and sodium hydroxide, with or without magnesium sulfate, in the absence of magnesium hydroxide, on the other hand. Wet zero span tensile

20 strength is measured in km using a Pulmac wet zero-span tensile apparatus.

$E_{op}$  and  $E_p$  bleaching are typically part of a broader overall chemical pulp bleaching sequence. Thus, there can be one or more additional chemical pulp bleaching stages that occur prior to  $E_{op}$  and  $E_p$  bleaching, as well as one or more additional chemical pulp bleaching stages that occur subsequent to  $E_{op}$  and  $E_p$

25 bleaching. Usually, these additional chemical pulp bleaching stages are conducted employing conventional bleaching technology utilizing bleaching chemicals such as  $ClO_2$ ,  $O_2$ ,  $Cl_2$  and peroxide.

The foregoing and other objects, features and advantages of the invention will become more apparent from the detailed description of a preferred

30 embodiment of the invention below which proceeds with reference to the accompanying drawings.

## DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram comparing pulp brightness for various levels of bleaching solution in an  $E_{op}$  bleaching process.

5        FIG. 2 is a schematic diagram comparing pulp viscosity for various levels of bleaching solution in an  $E_{op}$  bleaching process.

FIG. 3 is a schematic diagram comparing pulp wet zero-span tensile strength for various levels of bleaching solution in an  $E_{op}$  bleaching process.

10        FIG. 4 is a schematic diagram comparing pulp COD for various levels of bleaching solution in an  $E_{op}$  bleaching process.

## DETAILED DESCRIPTION OF THE PRESENT INVENTION

As set forth in Tables I-III, an aqueous slurry containing magnesium hydroxide was employed as a partial substitution for caustic soda and a complete replacement for magnesium sulfate in the extraction-oxygen-peroxide stage ( $E_{op}$ ) of the bleaching of northeast softwood kraft pulp. More specifically, laboratory experiments examined the bleachability of the pulp through a complete  $DE_{op}DE_pD$  bleach sequence with complete replacement of magnesium sulfate and partial substitution of NaOH on an  $OH^-$  molar basis using CellGuard™ OP (see description of CellGuard™ OP below) in the  $E_{op}$  stage. Three magnesium hydroxide substitution levels were evaluated in the  $E_{op}$  stage: 0%, 25%, and 50% of the  $OH^-$  derived from CellGuard™ OP and the balance from NaOH.

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In Table III, an aqueous slurry containing magnesium hydroxide was also employed as a partial substitution for caustic soda and a complete replacement for magnesium sulfate in the extraction-peroxide stage ( $E_p$ ) of the bleaching of northeast softwood kraft pulp. More specifically, laboratory experiments examined the bleachability of the pulp through a complete  $DE_{op}DE_pD$  bleach sequence with complete replacement of magnesium sulfate and partial substitution of NaOH on an  $OH^-$  molar basis using CellGuard™ OP (see description of CellGuard™ OP below) in both the  $E_{op}$  and  $E_p$  stages. Four magnesium hydroxide

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substitution levels were evaluated in the  $E_p$  stage: 0%, 25%, 50%, 75% and 100% of the  $OH^-$  derived from CellGuard™ OP and the balance, if any, from NaOH.

Bleaching experiments for the  $E_{op}$  stage were performed in a 2-liter, medium consistency oxygen reactor equipped with a mixer. The oxygen reactor was treated with nitric acid to passivate the surface to avoid contamination from metals. The  $D_0$ ,  $D_1$ ,  $E_p$ , and  $D_2$  stages were performed by traditional bag bleaching methods. The brownstock kraft pulp to be bleached had a kappa number of 29.2, a brightness of 26.9% ISO, and viscosity of 48.0 cps. This kraft pulp was bleached under the conditions outlined in Tables I-III. Chemical dosages were based on the weight of oven-dried pulp. The experimental procedure for each stage is summarized as follows:

$D_0$  Stage. Standard conditions as set forth in Tables I-III were employed for the  $D_0$  stage. The kappa factor was adjusted with 2.44%  $ClO_2$  to reach the desired kappa number out of the  $D_0$  stage. The pulp was then washed to pH 7.5.

$E_{op}$  Stage. After the  $D_0$  stage, the pulp was extracted with a conventional  $E_{op}$  stage which employed 1.7% NaOH and 0.1%  $MgSO_4$ . For comparison purposes in Tables I and II, bleaching experiments using CellGuard™ OP as a replacement for  $MgSO_4$  and as a partial substitute for NaOH were conducted. Caustic soda replacement was based on an  $OH^-$  molar basis. For example, at 25% substitution where 25% of the  $OH^-$  comes from  $Mg(OH)_2$ , the respective alkali dosages used were 1.275% NaOH and 0.31% CellGuard™ OP. Caustic soda contains 42.51% by weight  $OH^-$  ions while magnesium hydroxide contains 58.32% by weight  $OH^-$  ions. For the  $E_{op}$  stage in Tables I-III, bleaching occurred at 138 kPa of  $O_2$  pressure for 20 minutes followed by bleaching at atmospheric pressure for the remaining 40 minutes.

Martin Marietta Magnesia Specialties, LLC is the manufacturer of CellGuard™ OP Magnesium Hydroxide Slurry for use in pulp bleaching. The CellGuard™ OP Magnesium Hydroxide Slurry, which is produced from a dolomitic lime and magnesium brine process, contains 62% by weight  $Mg(OH)_2$  solids suspended in water. The purity of the magnesium hydroxide is over 98% with low levels of transition metals. This product has a fine particle size (3 microns as

measured by Micromeritics Sedigraph 5100) which promotes high reactivity and excellent suspension stability.

TABLE I – CONDITIONS FOR EACH BLEACHING STAGE

Stage	Pulp Consistency %	Time (min)	Temp (°C)	Pressure (kPa)	Chemical % on O.D. pulp
D <sub>0</sub>	12	45	60	----	2.44% ClO <sub>2</sub>
E <sub>op</sub>	12	60	70	138 kPa of O <sub>2</sub> for 20 min, then atm	0.5% H <sub>2</sub> O <sub>2</sub> 1.7% NaOH or Mg(OH) <sub>2</sub> /NaOH 0.1% MgSO <sub>4</sub> (for Control only)
D <sub>1</sub>	12	180	80	----	1.2% ClO <sub>2</sub>
E <sub>p</sub>	12	40	70	----	0.15% H <sub>2</sub> O <sub>2</sub> 0.5% NaOH
D <sub>2</sub>	12	100	80	----	0.6% ClO <sub>2</sub>

5            D<sub>1</sub>-E<sub>p</sub>-D<sub>2</sub> Stages (Tables I and II)-Standard conditions were employed for the D<sub>1</sub>-E<sub>p</sub>-D<sub>2</sub> stages shown in Tables I and II. The pulp and filtrate following each bleaching stage were tested for ISO brightness and end pH, respectively. The pH of the residual liquor was determined using a pH meter and appropriate buffer solutions to calibrate the pH meter. Pulp samples from the E<sub>op</sub>, D<sub>1</sub>, and D<sub>2</sub> stages  
10 were tested for viscosity and wet zero-span tensile strength. The respective filtrates were analyzed for chemical oxygen demand (COD).

After the D<sub>0</sub> stage and washing step, the kappa number decreased from 29.2 to 11.9. Pulp brightness increased from 26.9% ISO to 35.9% ISO. The effects of CellGuard™ OP substitution in the E<sub>op</sub> stage on each of the pulp  
15 parameters were measured. Table II contains a summary of results for each bleaching test performed.

FIG. 1 compares pulp brightness for the various levels of CellGuard™ OP substitution in the E<sub>op</sub> stage. The data shows the increasing trend in brightness with each subsequent bleaching stage for all substitution cases. The control  
20 sample, which employed 100% OH<sup>-</sup> from NaOH (or 0% OH<sup>-</sup> from CellGuard™ OP)

and  $\text{MgSO}_4$ , yielded an increase in brightness from 62.1% ISO after the  $E_{op}$  stage to a final pulp brightness of 90.8% ISO after the  $D_2$  stage.

At 25% substitution with CellGuard™ OP in the  $E_{op}$  stage, brightness after this bleaching step (60.1% ISO) was lower than the control. However, equivalent  
5 final pulp brightness after the  $D_2$  stage resulted in 90.5% ISO at the same  $\text{ClO}_2$  and  $\text{H}_2\text{O}_2$  charge in the  $D_1$  and  $E_p$  stages respectively as the control sample.

At 50% substitution with CellGuard™ OP, Figure 1 shows that the brightness after the  $E_{op}$  stage was 59.7% ISO. Even with the use of a mild alkali in the extraction stage which lowers the bleaching pH to 10.1 for 25% substitution  
10 and 9.3 for 50% substitution, comparable final brightness was achieved as evidence by the final 89.9% ISO brightness result after the  $D_2$  stage.

At the end of the  $E_{op}$  stage, the control sample yielded a pulp viscosity of 27.8 cps. As shown in FIG. 2, both the 25% and 50% substitution runs with CellGuard™ OP produced higher viscosity results of 28.6 cps and 29.3 cps  
15 respectively after the  $E_{op}$  stage. These results indicate that CellGuard™ OP serves a dual role as a peroxide activator and cellulose protector. In a conventional  $E_{op}$  system where NaOH and  $\text{MgSO}_4$  are utilized, CellGuard™ OP  $\text{Mg}(\text{OH})_2$  can reduce the NaOH consumption and eliminate  $\text{MgSO}_4$ . As seen in FIG. 2, the control sample's final viscosity was 16.5 cps, the 25% and 50% substitution samples with  
20 CellGuard™ OP produced pulps with respective viscosities of 17.5 cps and 18.6 cps. By utilizing CellGuard™ OP Magnesium Hydroxide in the  $E_{op}$  stage, a one to two point increase in pulp viscosity over the conventional  $E_{op}$  stage was achieved.

Fiber strength was maintained in both CellGuard™ OP substitution cases as shown in Figure 3. Wet zero-span tensile strength for all cases ranged from 10.9 –  
25 11.0 km for the  $E_{op}$  stage, 10.2 – 10.6 for the  $D_1$  stage, and 10.3 – 10.4 km for the  $D_2$  stage.

High chemical oxygen demand (COD) is generated in the  $E_{op}$  stage where the most of the extraction occurs (see FIG. 4). Partially substituting the NaOH charge with a weak alkali such as  $\text{Mg}(\text{OH})_2$  reduces the organic loading in the  
30 effluent from the  $E_{op}$  stage. The higher substitution rate with CellGuard™ OP



yielded a noticeable reduction in COD when compared to the control sample. The control sample generated 4635 mg/L COD versus 4105 mg/L COD for the 50% substitution case, which represents an 11% reduction. Lower COD loading can contribute to reduced effluent treatment costs downstream.

5 By employing partial substitution of CellGuard™ OP Magnesium Hydroxide Slurry for caustic soda and eliminating magnesium sulfate in the E<sub>op</sub> stage, a strong alkali is present to facilitate lignin removal while a mild alkali is added to promote peroxide bleaching and cellulose protection. CellGuard™ OP can replace up to 50% of the caustic soda requirement in the E<sub>op</sub> stage producing final pulp from the 10 D<sub>2</sub> stage with similar brightness, permanganate number, and wet zero-span tensile strength as pulp bleached with a 100% caustic soda charge.

At 50% substitution of caustic soda, the use of CellGuard™ OP improves the pulp viscosity by 12% and reduces the COD after the E<sub>op</sub> stage by 11%. Since only 0.73 kg of magnesium hydroxide provides the equivalent amount of hydroxyl 15 ions as 1 kg of caustic soda, CellGuard™ OP reduces bleaching costs in many cases. At no added cost beyond the amount required for caustic soda replacement, CellGuard™ OP also eliminates the need for magnesium sulfate for further reduction in chemical costs.

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**TABLE II**  
RESULTS OF PARTIAL SUBSTITUTION OF  
CAUSTIC SODA WITH MAGNESIUM HYDROXIDE SLURRY  
IN THE EOP STAGE OF A DEopDEpD BLEACH SEQUENCE

	Stage	Chemical (% on pulp) <sup>1</sup>	Time (min)	Temp (°C)	Pressure (kPa)	End pH	ISO Bright- ness (%)	Viscosity(cp)	K No.	Wet Zero-Span (km)	COD (mg/l)
Brown-stock							26.9	48.0	(29.2 as kappa)	12.5	
D <sub>0</sub> Stage	D <sub>0</sub>	0.22 kf (2.44% ClO <sub>2</sub> )	45	60		2.3 <sup>2</sup>	35.9		7.4 (11.9 as kappa)		
Control NaOH + MgSO <sub>4</sub>	Eop	0.5% H <sub>2</sub> O <sub>2</sub> 1.7% NaOH 0.1% MgSO <sub>4</sub> 0% Mg(OH) <sub>2</sub>	60	70	138 kPa O <sub>2</sub> for 20 min, then atm	11.3	62.1	27.8	3.1	10.9	4635
	D <sub>1</sub>	1.2% ClO <sub>2</sub>	180	80		2.3	80.2	21.4	1.1	10.2	1352
	Ep	0.15% H <sub>2</sub> O <sub>2</sub> 0.5 % NaOH	40	70		11.4	86.0				
	D <sub>2</sub>	0.6% ClO <sub>2</sub>	100	80		3.3	90.8	16.5	0.6	10.3	176
25% Substitution CellGuard™ in Eop	Eop	0.5% H <sub>2</sub> O <sub>2</sub> 1.275% NaOH 0.31% Mg(OH) <sub>2</sub>	60	70	138 kPa O <sub>2</sub> for 20 min, then atm	10.1	60.1	28.6	3.4	10.8	4555
	D <sub>1</sub>	1.2% ClO <sub>2</sub>	180	80		2.3	78.9	22.1	1.3	10.3	1326
	Ep	0.15% H <sub>2</sub> O <sub>2</sub> 0.5 % NaOH	40	70		11.4	85.3				
	D <sub>2</sub>	0.6% ClO <sub>2</sub>	100	80		3.3	90.5	17.5	0.6	10.2	
50% Substitution CellGuard™ in Eop	Eop	0.5% H <sub>2</sub> O <sub>2</sub> 0.85% NaOH 0.62% Mg(OH) <sub>2</sub>	60	70	138 kPa O <sub>2</sub> for 20 min, then atm	9.3	59.7	29.3	3.5	11.0	4105
	D <sub>1</sub>	1.2% ClO <sub>2</sub>	180	80		2.3	76.3	22.0	1.4	10.6	1420
	Ep	0.15% H <sub>2</sub> O <sub>2</sub> 0.5% NaOH	40	70		11.3	83.9				
	D <sub>2</sub>	0.6% ClO <sub>2</sub>	100	80		3.2	89.9	18.6	0.7	10.4	184

<sup>1</sup> % on oven-dried pulp

<sup>2</sup> After washing, pH was 7.5

All experiments were conducted at 12% pulp consistency.

- 5            E<sub>op</sub>-D<sub>1</sub>-E<sub>p</sub>-D<sub>2</sub> Stages (Table III)-Standard conditions were employed for the D<sub>1</sub> and D<sub>2</sub> stages of bleaching processes shown in Table III. In the experiments involving substitution of magnesium hydroxide for NaOH in the E<sub>p</sub> stage, magnesium hydroxide was substituted for all of the magnesium sulfate and a portion of the NaOH (25%, 50%, 75% or 100%). The E<sub>op</sub> stage employed a 50%  
10 substitution of magnesium hydroxide for NaOH, and 100% substitution for all of the magnesium sulfate, in all the bleaching experiments. The pulp and filtrate following each bleaching stage were tested for ISO brightness and end pH, respectively. The pH of the residual liquor was determined using a pH meter and appropriate buffer solutions to calibrate the pH meter. Pulp samples from the E<sub>op</sub>,  
15 D<sub>1</sub>, and D<sub>2</sub> stages were also tested for viscosity and K#. As seen in Table III, the final ISO brightness, viscosity and K# of the bleached chemical pulp of the process of the present invention is comparable or greater than the the final ISO brightness, viscosity and K# of bleached chemical pulp which is bleached with the same total amount of an E<sub>p</sub> aqueous bleaching solution comprising said peroxide compound  
20 and sodium hydroxide, but in the absence of magnesium hydroxide.

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Table III. RESULTS OF SUBSTITUTION OF CAUSTIC SODA  
AND MAGNESIUM SULFATE WITH MAGNESIUM  
HYDROXIDE SLURRY

In E<sub>op</sub> and E<sub>p</sub> Stages of a DE<sub>op</sub> DE<sub>p</sub>D Bleach Sequence

	Stage	Chemical %	Time (min)	T E M P	Pressure (psig)	Kappa	K# 25 ml	ISO Bright- ness %	Vis- cos- ity cp
BS	<u>Brownstock</u>					30.4		26.1	51.9
D After washing To 7.5 pH	D	0.22kf (2.54% ClO <sub>2</sub> )				13.7	8.6	34.3	48.2
CONTROL NaOH + MgSO <sub>4</sub> Sequence  E <sub>op</sub> & E <sub>p</sub> stages NaOH only	E <sub>op</sub> 100% OH- from NaOH	0.5%H <sub>2</sub> O <sub>2</sub> 1.7% NaOH 0.1% MgSO <sub>4</sub> 0% Mg (OH) <sub>2</sub>	60	70	138Kpa O <sub>2</sub> for 20 min. then atm		3.5	61.6	41.9
	D1	1.2% ClO <sub>2</sub>	180	80			1.3	79.6	29.8
	E <sub>p</sub> 100% OH- from NaOH	0.15%H <sub>2</sub> O <sub>2</sub> 0.48% NaOH 0% Mg (OH) <sub>2</sub>	40	70				86.4	
	D2	0.6% ClO <sub>2</sub>	100	80			0.6	90.7	22.0
Mg(OH) <sub>2</sub> Substitution Sequence  E <sub>op</sub> 50% Substitution  E <sub>p</sub> Varying Substitution	E <sub>op</sub> 50% OH- from Mg(OH) <sub>2</sub>	0.5%H <sub>2</sub> O <sub>2</sub> 0.85% NaOH 0.62% Mg (OH) <sub>2</sub>	60	70	138Kpa O <sub>2</sub> for 20 min. then atm		4.0	54.9	42.6
	D1	1.2% ClO <sub>2</sub>	180	80			1.6	74.9	32.9
	E <sub>p</sub> Control	0.15%H <sub>2</sub> O <sub>2</sub> 0.48% NaOH 0% Mg (OH) <sub>2</sub>	40	70				84.0	
	D2	0.6% ClO <sub>2</sub>	100	80			0.7	90.3	24.6

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Cont-  Mg(OH) <sub>2</sub> Substitution Sequence  E <sub>op</sub> 50% Substitution  E <sub>p</sub> Varying Substitution	E <sub>p</sub> 25% OH- from Mg(OH) <sub>2</sub>	0.15% H <sub>2</sub> O <sub>2</sub> 0.36% NaOH 0.09% Mg (OH) <sub>2</sub>	40	70				83.6	
	D2	-	100	80			0.7	90.2	24.6
	E <sub>p</sub> 50% OH- from Mg(OH) <sub>2</sub>	0.6% ClO <sub>2</sub>  0.15% H <sub>2</sub> O <sub>2</sub> 0.24% NaOH 0.18% Mg (OH) <sub>2</sub>	40	70				83.1	
	D2		100	80			0.8	89.9	25.2
	E <sub>p</sub> 75% OH- from Mg(OH) <sub>2</sub>	0.6% ClO <sub>2</sub>  0.15% H <sub>2</sub> O <sub>2</sub> 0.12% NaOH 0.26% Mg (OH) <sub>2</sub>	40	70				81.5	
	D2		100	80				89.5	25.3
	E <sub>p</sub> 100% OH- from Mg(OH) <sub>2</sub>	0.6% ClO <sub>2</sub>  0.15% H <sub>2</sub> O <sub>2</sub> 0% NaOH 0.35% Mg (OH) <sub>2</sub>	40	70				78.8	
	D2	0.6% ClO <sub>2</sub>	100	80			0.8	88.6	24.0